Run II Performance and Plans

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HEPAP Meeting

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Outline

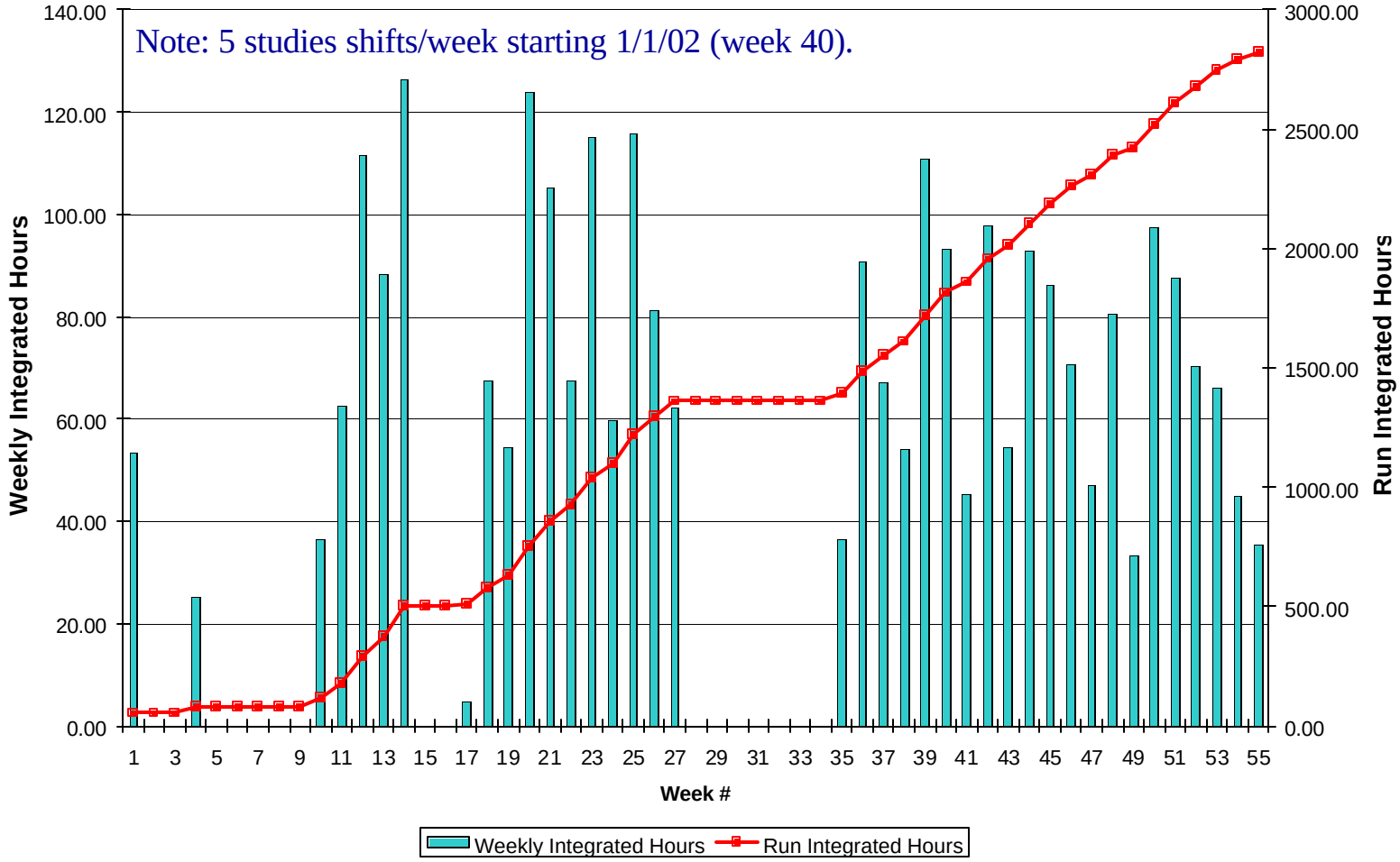
- Run II Goals
- Current Performance
- Progress Relative to the Run IIA plan
- Help
- Beyond 2002

Run II Goals
(Unchanged since January)

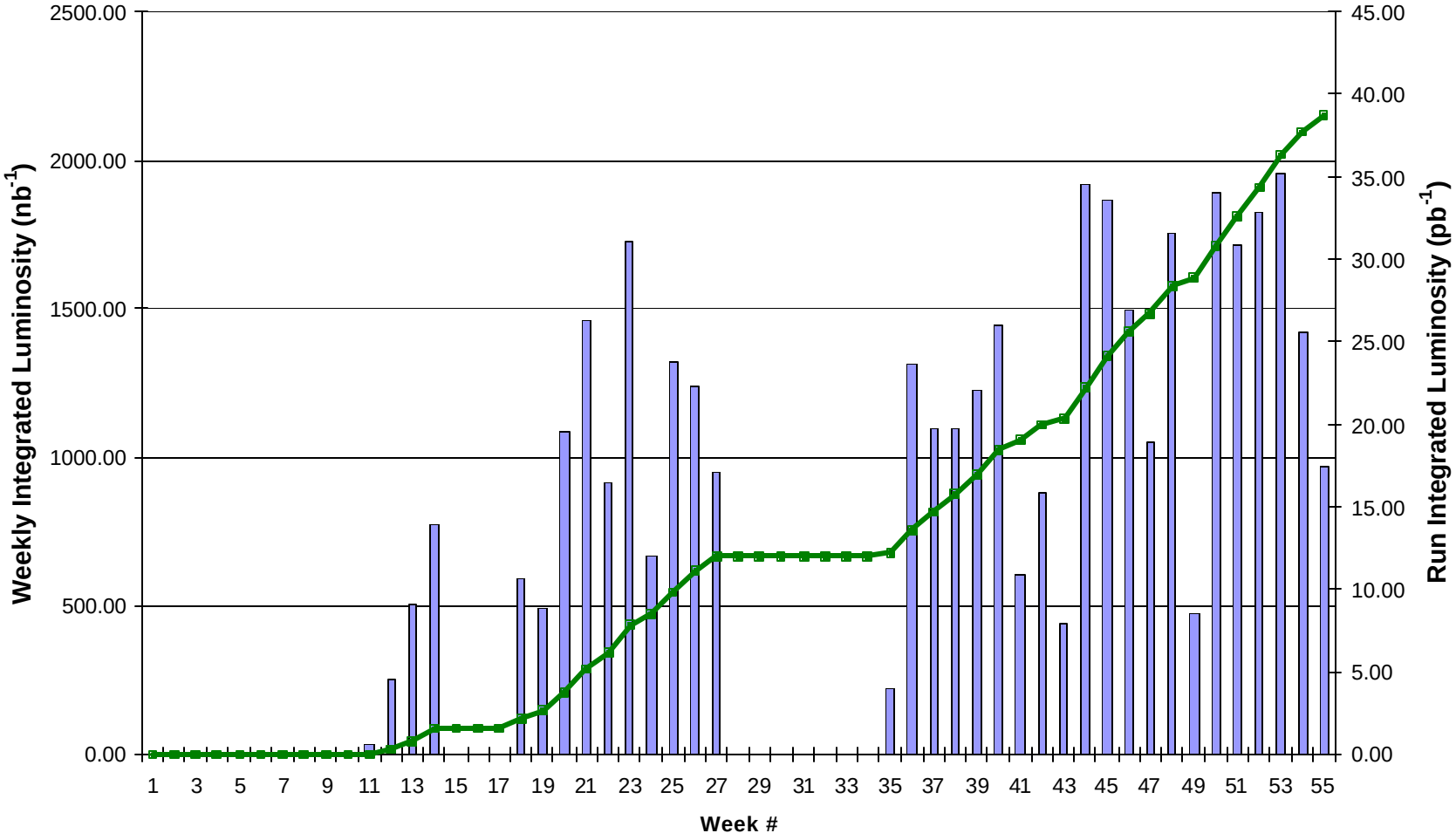
Run II has been split into Run IIA and Run IIB. While the breakpoint is somewhat arbitrary, as a practical definition:

- **Run IIA** refers to operations supported by the collider configuration envisioned during the Main Injector construction.
  - Luminosity:
    - 5×10^{31} (Main Injector Project baseline)
    - 8×10^{31} (renormalized when we exceeded our Run I goal by 60%)
    - 2×10^{32} (Recycler Ring incorporated into the Main Injector Project)
  - Integrated luminosity: 2 fb^{-1} over a 2-3 year period
- **Run IIB** refers to this configuration augmented by a number of (substantial) hardware upgrades required to push the luminosity well above 2×10^{32} and to support a total accumulation of approximately **$15 fb^{-1}$ prior to LHC data taking.**

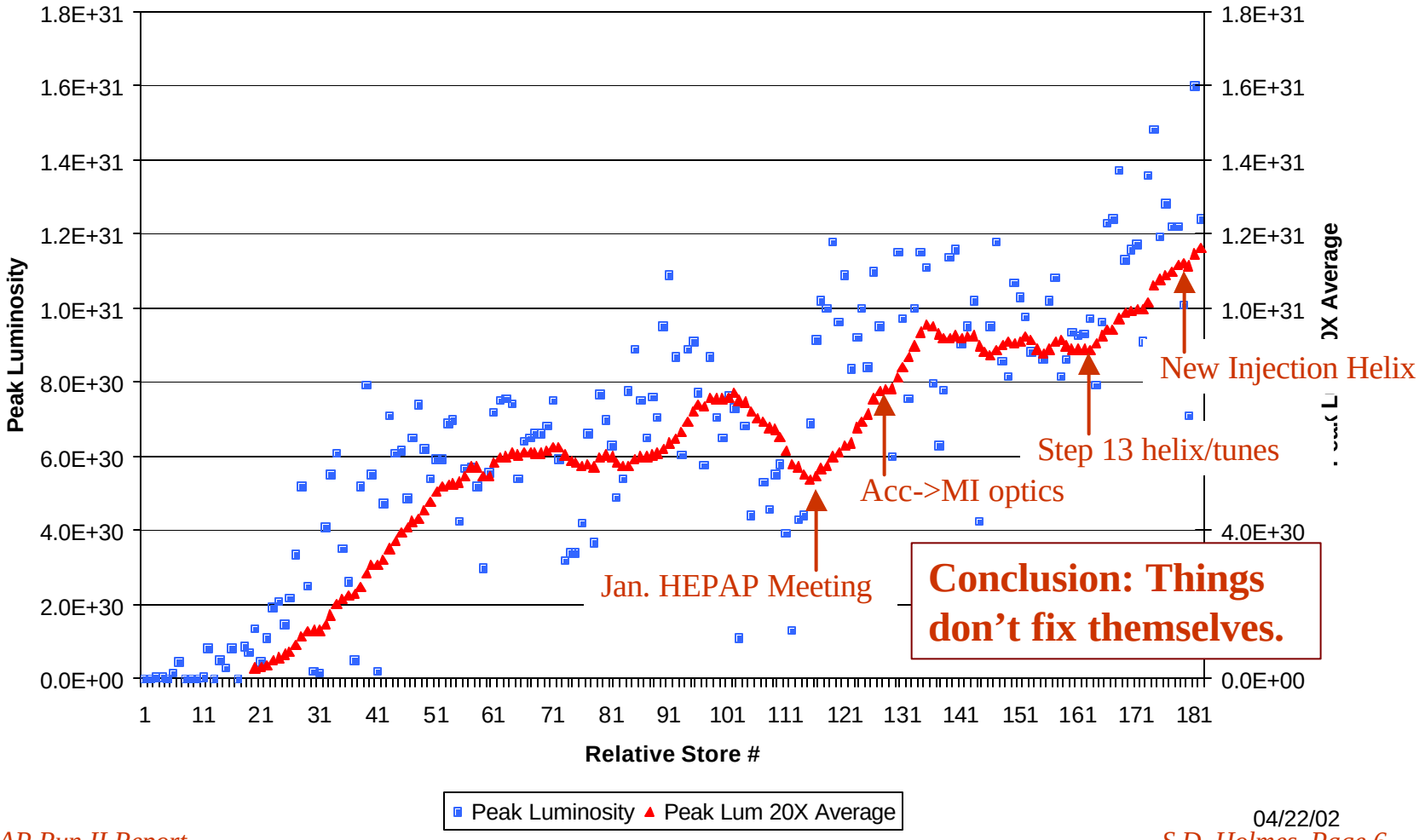
Current Performance
Store Hours



Current Performance
Integrated Luminosity



Current Performance
Luminosity



Current Performance
Comparison with Run IIA Goals

(http://www-bd.fnal.gov/lug/runII_handbook/RunII_index.html)

	Run IB	RunIIA Goal (wo/ recycling)	RunIIA (achieved*)	
Protons/bunch	2.30E+11	2.70E+11	1.65E+11	
Antiprotons/bunch	5.50E+10	3.00E+10	9.6E+09	
Total Antiprotons	3.30E+11	1.08E+12	2.93E+11	
Antiproton Production Rate	6.0E+10	2.0E+11	1.0E+11	$hour^{-1}$
Accumulator->150 GeV efficiency	0.80	0.90	0.75	
150 GeV -> Low? efficiency	0.80	0.90	0.47	
Accumulator -> low? efficiency	0.64	0.81	0.35	
Proton emittance (95%, norm)	23	20	15	?mm-mr
Pbar emittance (95%, norm)	13	15	15	?mm-mr
Beta @ IP	0.35	0.35	0.35	m
Beam Energy	900	1000	980	GeV
Bunches	6	36	36	
Longitudinal Emittance (protons)	5	3	4	eV-sec
Longitudinal Emittance (pbars)	5	3	4	eV-sec
Form Factor (Hourglass)	0.59	0.70	0.65	
Typical Luminosity	1.6E+31	8.08E+31	1.60E+31	$cm^{-2}sec^{-1}$

*"Achieved" refers to simultaneous performance. Best individual parameters are higher.

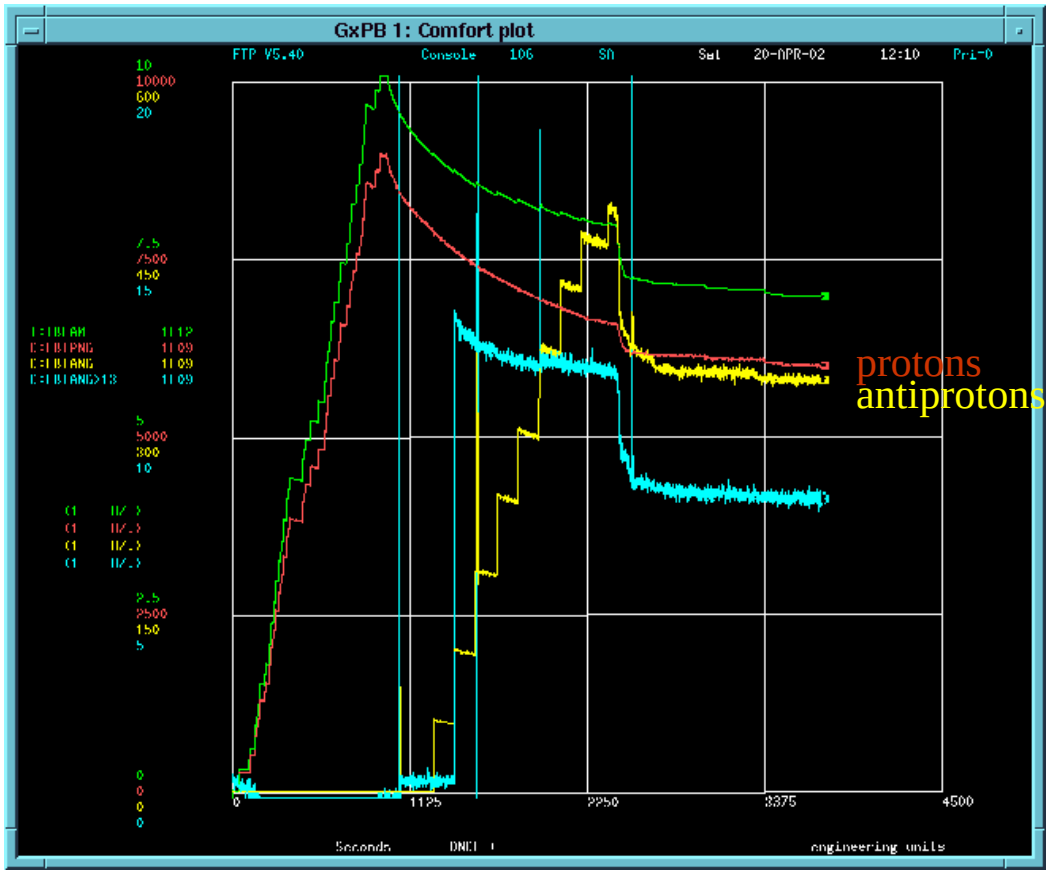
Current Performance
Commentary

- The following modifications have directly impacted luminosity performance since January meeting:
  - Modified Accumulator to Main Injector optics to provide better optical match.
  - Modified helix and tunes during step 13 of the low beta squeeze.
    - has allowed us to inject more protons without paying the same pbar penalty
  - New injection helix
  - Worth 15-25% each in performance
- We continue to devote 5 shifts/week to studies.
  - Gaining a much better handle on the issues limiting performance and moving towards solutions (see subsequent discussion).
- We continue to follow the "Church" plan described in January, with modification as necessary.

Current Performance
Macroscopic Indicators

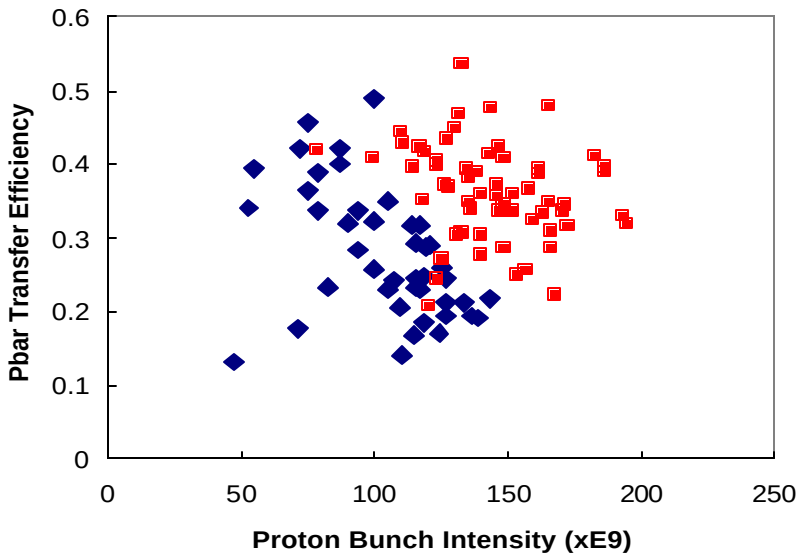
Typical shot showing:

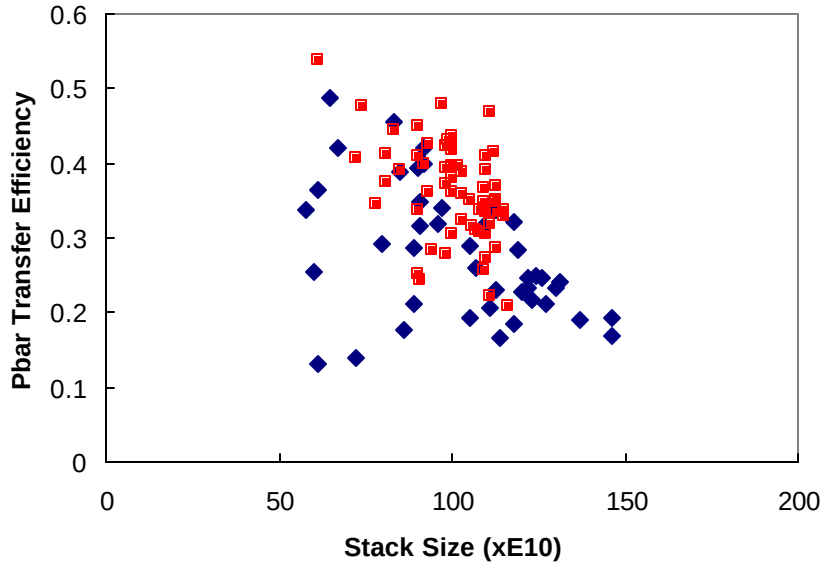
- Loading of 36 proton bunches
- Loading of 9x4 antiproton bunches at 150 GeV
  - Few hour beam lifetime on both proton and pbar helices
- Significant beam loss at start of acceleration
- Very little loss (now) during low beta squeeze



Current Performance
Macroscopic Indicators

- Current **antiproton production rate is sufficient** to support a luminosity in the **4-6x10^{31} cm^{-2}sec^{-1}** range.
- Protons are roughly 70% of Run II goal
- Antiprotons are roughly 33% of Run II goal
  - Transfer efficiency accumulator to low beta remains terrible, but better than in January (■ = since January HEPAP).





Current Performance
Underlying Issues/Protons

- Protons (Goal = 270E9/bunch, achieved = 196E9/bunch in collision)
  - Have achieved 330E9/bunch (routinely) in Main Injector
    - Coalescing efficiency is OK (~80%)
    - Longitudinal emittance is large (4 eV-sec, should be 2-3)
    - Transverse emittance at 300E9/bunch is OK (~16? mm-mr)
  - MI -> Tevatron transfer efficiency is poor (80%)
    - 100% efficiency if uncoalesced
  - Lifetime at 150 GeV (2-3 hours) and acceleration efficiency (90%) are poor
    - Tevatron aperture? Longitudinal emittance? Vacuum?
  - Antiproton lifetime at 150 GeV in Tevatron is (still) very sensitive to proton intensity
  - We are generating beam losses that are hampering the performance of the experiments (CDF in particular)
    - Loss of beam (protons mostly) from rf buckets

Current Performance
Underlying Issues/Antiprotons

- Antiprotons (Goal = 30E9/bunch, achieved 11E9 in collision)
  - Accumulator transverse emittances roughly twice as large as in Run I
    - Heating source?
  - Accumulator->MI transmission efficiency is good (92-97%)
  - MI acceleration is excellent (100%)
  - MI coalescing efficiency is marginal (75-80%)
    - Very sensitive to antiproton longitudinal emittance
  - MI->Tev transfer efficiency is bad (75%)
    - ~90-95% if uncoalesced
  - Tevatron 150 GeV lifetime is poor (2-3 hours)
    - Aperture? Emittance growth?
  - Tevatron acceleration efficiency is poor (80%)
  - Low beta squeeze efficiency is good (95%)

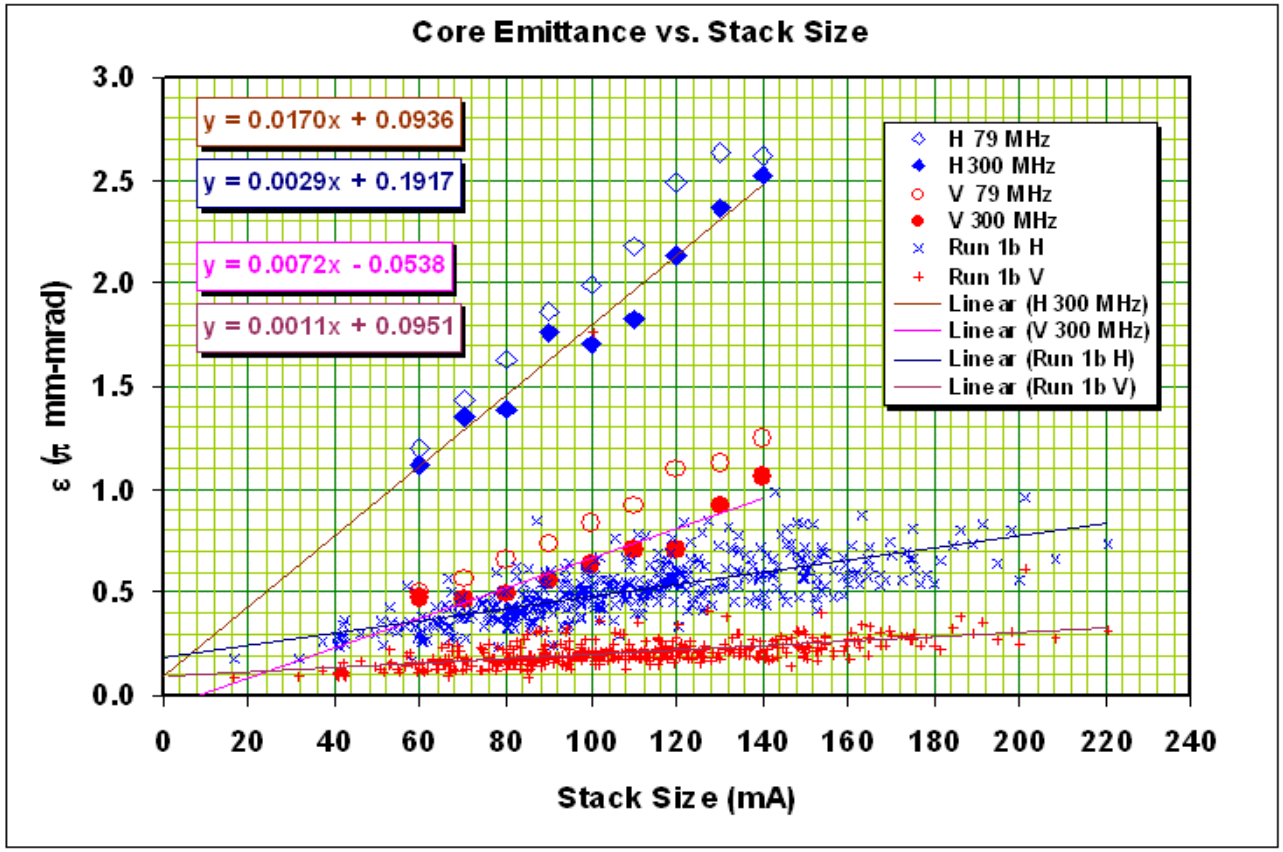
Current Performance
Underlying Physics Issues

- Three primary accelerator physics issues appear to be emerging, and are being dealt with:
  - Accumulator emittance/heating
    - Intrabeam scattering appears implicated
  - Long range beam-beam in the Tevatron
    - Manifested as poor antiproton lifetime at 150 GeV
    - Once collision configuration achieved, this is not impacting performance
    - Contribution to lifetime from vacuum under investigation
  - Proton longitudinal emittance
    - Looks like this is beamloading ? solution is compensation
- These issues interconnect many of the individual performance parameters

? Progress requires attacking everything in parallel.

Current Performance

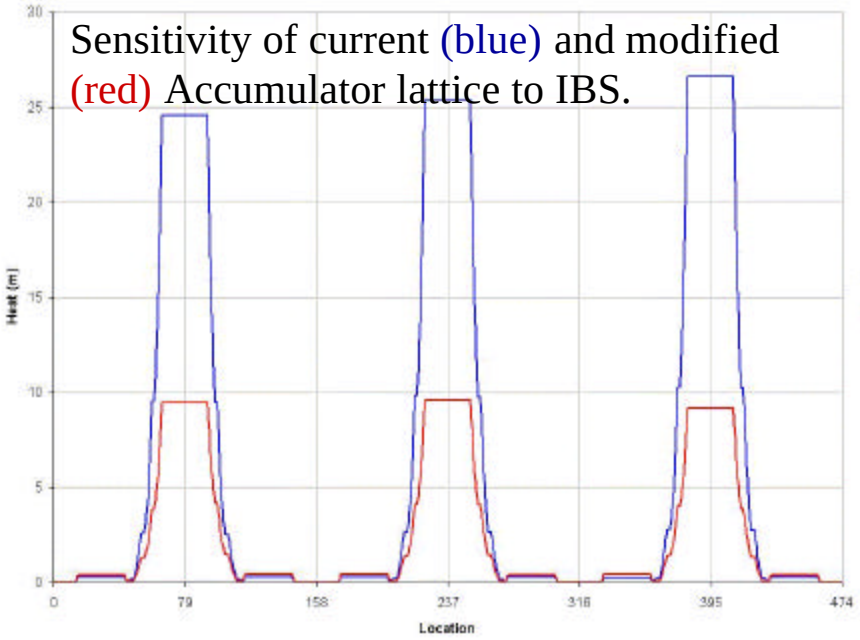
Underlying Physics Issues/Antiproton Emittance

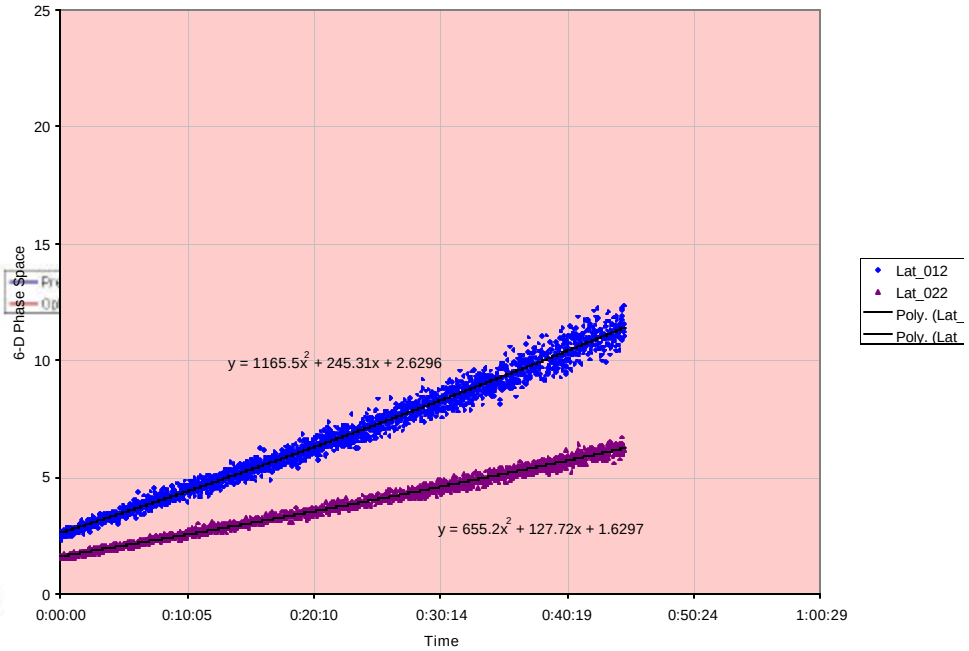


- Symptoms
  - Emittances significantly larger than Run I
  - Horizontal significantly larger than vertical
- What's changed?
  - Lattice modified to support higher stacking rate.
  - Suspect IBS

Current Performance

Underlying Physics Issues/Antiproton Emittance





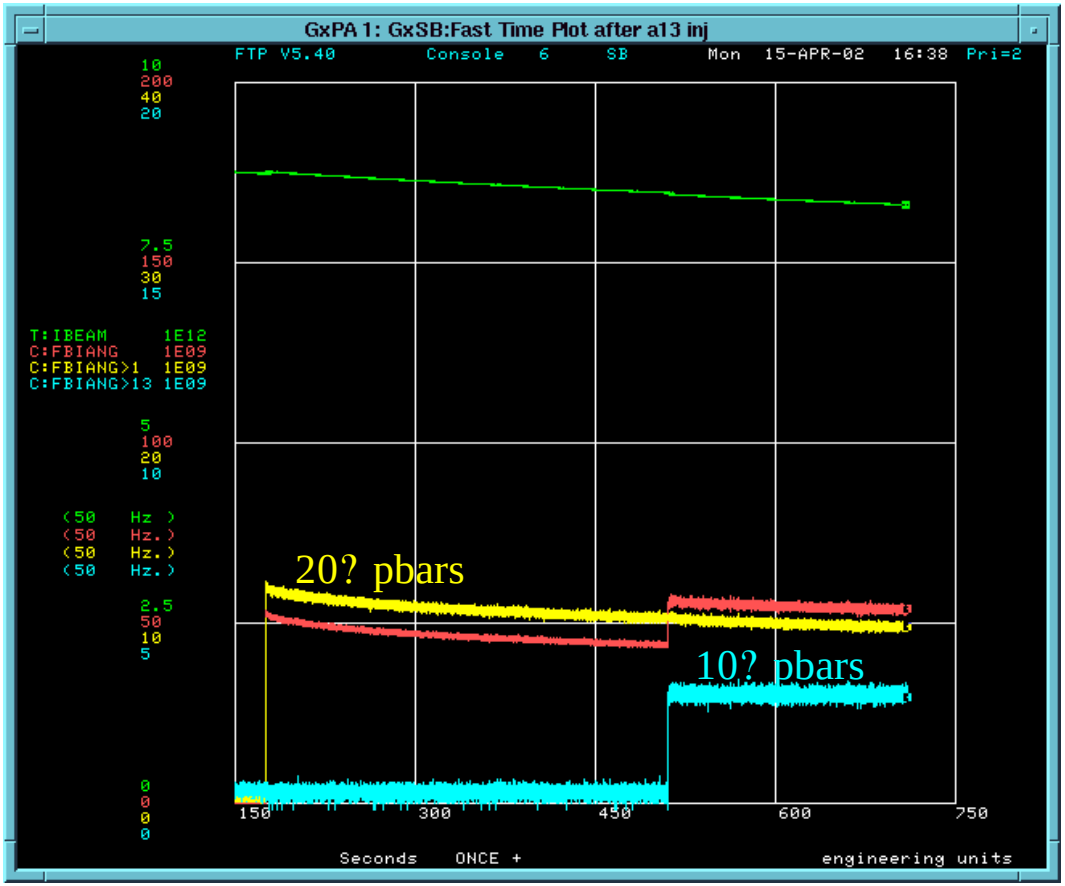
Solutions (note: modified lattice cannot be used for stacking)

- Increase core cooling (in process)
- Lattice change as part of shot setup (under implementation)
- Ultimate solution is integration of the Recycler into operations.

Current Performance

Underlying Physics Issues/Long-range beam-beam

- Symptoms
  - Poor antiproton lifetime at 150 GeV
    - ✍Highly dependent upon proton bunch intensities and pbar emittance
  - Beam loss during low-? squeeze
    - ✍Highly dependent upon proton bunch intensities
    - ✍Solved
  - No negative effect on performance observed once beams are in collision



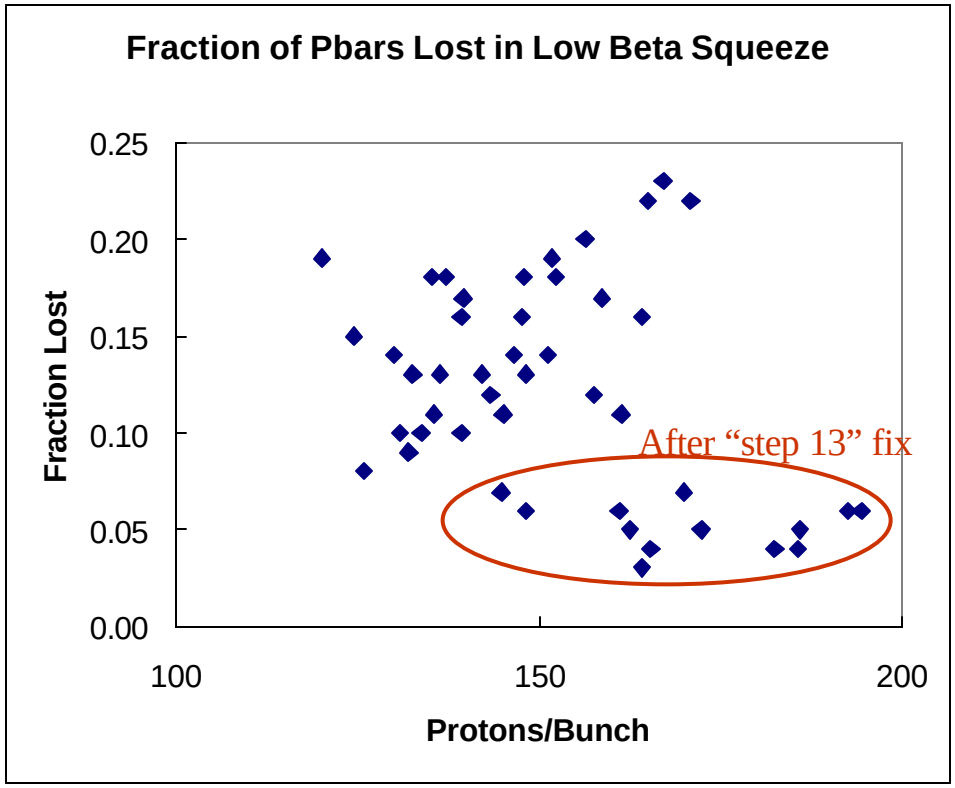
Current Performance

Underlying Physics Issues/Long-range beam-beam

Solutions

- Modify injection helix (in process)
- Increase aperture (looking at removing C-0 abort)
- Decrease antiproton emittance (see prior discussion)

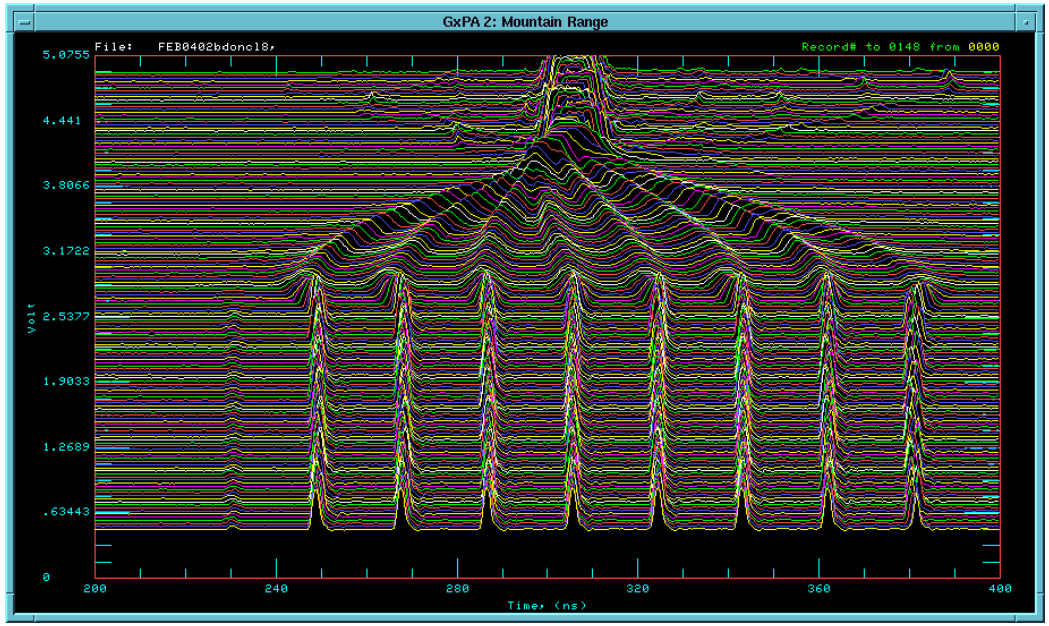
Note: Success in dealing with the "step 13" loss demonstrates LRBB is amenable to a strategy based on helix and tune adjustment.



Current Performance

Underlying Physics Issues/Longitudinal Emittance

- Symptoms
  - Both proton and antiproton longitudinal emittances are larger than they should be (by 50-100%)
    - Beam loss at start of Tevatron acceleration
    - Poor pbar coalescing efficiency
    - Modest loss in luminosity due to “hourglass” effect
    - Effect on 150 GeV lifetime?



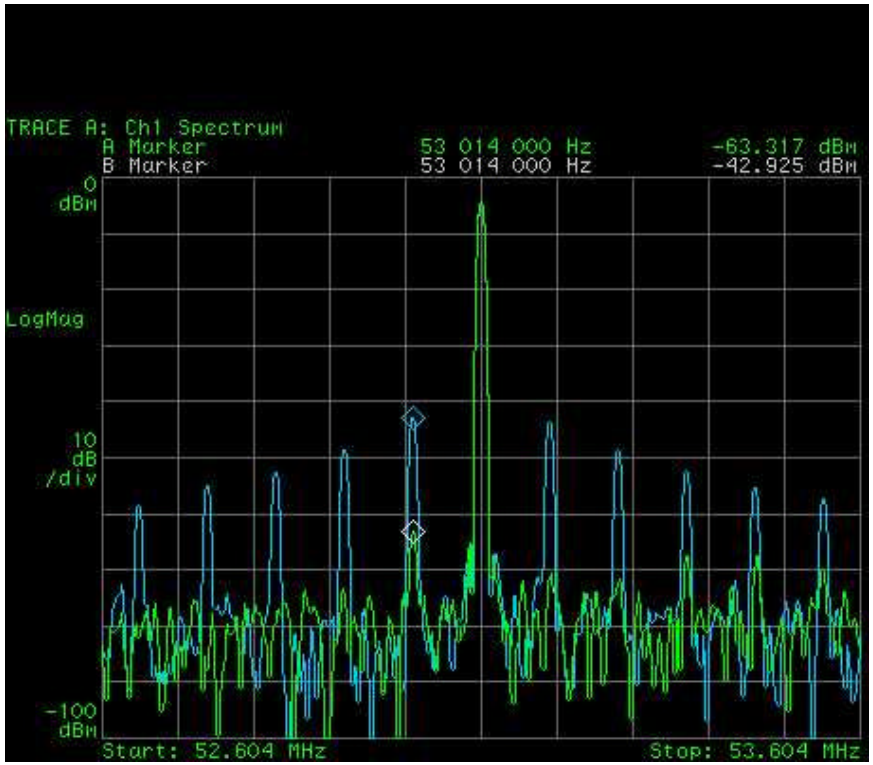
  - Proton emittances are suffering from beamloading distortions during the coalescing process in Main Injector.
  - Antiproton emittances reflect operations with low longitudinal density in the Accumulator to keep the transverse emittances manageable.

Current Performance

Underlying Physics Issues/Longitudinal Emittance

Solutions

- Booster longitudinal dampers (implemented)
- 53 MHz beamloading compensation
  - Implemented on two (of 18) MIRF stations
  - 20 dB signal suppression observed (good enough)
- Decrease antiproton emittances (see prior discussion)
- 2.5 MHz antiproton acceleration in the Main Injector (under study)



Progress Relative to the Run IIA Plan

General Strategy (modified slightly since January)

January 1 – July 1

- Improve antiproton efficiency from Accumulator to Tevatron low-?
- Improve proton intensity at Tevatron low-?
- Commission Recycler parasitically
- Minimize access time

June (or whenever cooling tanks are ready)

- Shutdown to install new Accumulator transverse core cooling (2 weeks)

June – December 31

- Improve stacking rate
- Shutdown for continuing Recycler vacuum work (tentatively scheduled September 30-November 10)
- Integrate Recycler into operations
- Minimize accesses

Progress Relative to the Run IIA Plan

At the January meeting I presented a condensed version of the plan, and associated milestones, that was assembled by the Beams Division for the achievement of the initial (pre-Recycler) Run IIA goal by the end of the year. Progress relative to this plan is presented in the next several slides.

Plan for achieving Run IIA goals
Studies/Hardware

- Protons

Proton intensity		
Recommission Booster dampers	2/15/02	Complete
Tune up Booster $2B cycles	3/1/02	Complete
Coalescing efficiency		
FBI calibration	Done	
Longitudinal emittance calculation algorithm	3/1/02	Complete
Eliminate cogging loss	Done	
Implement beamloading compensation	3/15/02	In process
Tev 150 GeV lifetime		
Measure/improve momentum aperture on helix	2/15/02	Complete
Fix pbar injection bumps to eliminate proton loss	2/15/02	Complete
Commission longitudinal dampers	Done	
Revised lattice for injection helix?	9/1/02	In process
Tev acceleration/store		
Commission Tev transverse dampers	6/1/02	

Plan for achieving Run IIA goals

Studies/Hardware

- **Antiprotons**

Stacking rate		
Commission compensation leg in stacktail system	11/1/02	
Accumulator emittance		
Commission and calibrate 300 MHz emittance monitors	2/15/02	Complete
Continue damper investigation and search for noise sources	3/1/02	In Process
Understand source of positive chromaticity at core	3/1/02	Complete
Modify or repair magnets if required	4/15/02	Under study
Complete IBS calculations and compare with Run I	2/15/02	In Process
Try wider core momentum width for shots	In progress	
Install and commission new transverse core cooling arrays	8/15/02	Aiming for 6/15
Modify Accumulator lattice for reduced IBS	5/15/02	
Accumulator->MI transfer		
Modify optics of AP3, AP1, P2, P1	2/15/02	Complete
Commission MI pbar injection damper	3/15/02	Late

Plan for achieving Run IIA goals
Studies/Hardware

- Antiprotons (continued)

Coalescing Efficiency		
FBI calibration	Done	
Fix Accumulator rf unstacking mechanics	4/15/02	Complete
Tune up coalescing efficiency	4/15/02	Complete
MI->Tev transfer		
Fix antiproton injection bumps/kicker settings	3/1/02	Complete
Commission BLT for antiprotons	Done	
Measure A1 beamline optics/retune transfer	3/1/02	Complete
Commission new DCCT for Tev bus and investigate stability of MI-Tev energy match	2/15/02	Not needed
Tev 150 GeV lifetime		
Understand/improve momentum aperture on helix	3/1/02	Complete
Document antiproton transverse emittances in MI	Done	
Decommission/remove C-0 extraction equipment	11/10/02	
Tev low beta squeeze		
Accelerate squeeze and/or adjust tunes through step 13	3/1/02	Complete

Luminosity Projection for 2002

Performance Milestones

Milestone 1: 2/15

150E9/bunch protons; luminosity =1.77E31

Milestone 2: 3/15

150E9/bunch protons; 50% pbar xfer eff.; luminosity=2.46E31

Milestone 3: 4/15

150E9/bunch protons; 70% pbar xfer eff.; luminosity=3.44E31

196E9/bunch protons; 40% pbar xfer eff.; luminosity=~~1.60E31~~ 1.64E31

Milestone 4: 6/01

200E9/bunch protons; 70% pbar xfer eff.; luminosity=3.93E31

Milestone 5: 8/15

200E9/bunch protons; 80% pbar xfer eff.; luminosity=4.65E31

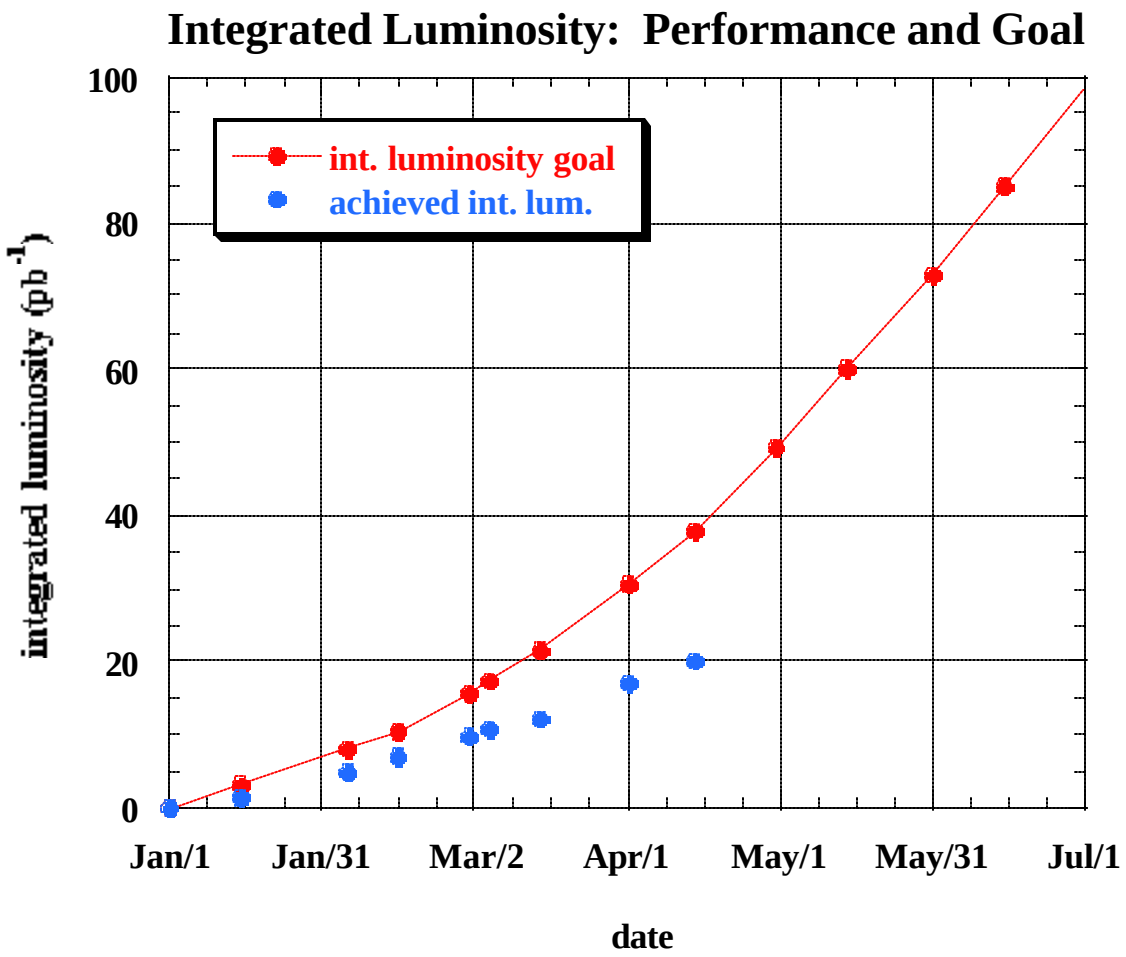
Milestone 6: 10/15

250E9/bunch protons; 80% pbar xfer eff.; luminosity=5.82E31

Milestone 8: 12/31

Run IIa/initial goals; luminosity=8.6E31

Luminosity Projection for 2002
Comparison to Actual



Help

The Beams Division staff is working extremely hard on Run II. However, it is clear that if we had more people we could both progress more rapidly and start freeing people up to work on Run IIB.

- We are fielding large number of offers of help, both from within the laboratory, from the detector collaborations, and from other laboratories.
- These offer are deeply appreciated, and we are working actively to get help integrated effectively.
  - Need three-fold match of capabilities, need, and internal contact
  - Requires case-by-case facilitation
  - Complete list of instrumentation and damper needs generated for basis of discussions

Help

- We are starting to achieve success with integration of laboratory resources outside the Beams Division
  - PPD and CD staff: Shot Data Analysis and instrumentation projects.
  - Stephen Pordes transfer from PPD (Deputy) to Beams Division with responsibility for coordination of instrumentation
  - Initiation of "wise-person" advisory group incorporating senior people with previous experience (Peoples, Edwards, Limon, Tollestrup, Finley, Harrison(BNL))
- And we are starting to establish assignments with the outside
  - Calculational assignments made in the SLAC accelerator theory group
  - Visit from LBNL senior staff week of May 6
  - Invitations to senior accelerator scientists to "spend your summer vacation at Fermilab"
  - A few more things in the works that can't yet be publicized

Run IIA Beyond 2002

The plan we are executing leads to the maximum luminosity we believe we can obtain **without antiproton recycling**. The next steps:

- Integrate Recycler into operations (wo/recycling) Jan 2003
  - No specific luminosity advantage to this step unless the Accumulator continues to choke at high stacks, in which case this will take heat off the Accumulator (likely)
  - Initiate commissioning of the recycling operation
- Integrate antiproton recycling Fall-Winter 2003
  - This will allow us to achieve 2×10^{32} luminosity with 36x36 bunches once we achieve an overall recycling efficiency of 50%
- Initiation of Run IIB upgrades Jan 2004

Summary

Collider Run II is the most important activity we are engaged in at Fermilab.

- Issues uncovered during initial Run II operations are being pursued systematically. We expect to achieve the luminosity goal established with the Main Injector project by the end of this year.
  - There is no “silver bullet”
  - Most serious underlying issues are:
    - Antiproton transverse emittance
    - Tevatron transfer/acceleration efficiencies, beam lifetime at 150 GeV
    - Longitudinal emittance (both beams)
- While initial Run II operations have been disappointing, we have seen approximately 60% improvement in performance since January.
  - Derived from specific improvements to the complex
  - Many more to go

Summary

- We are starting to integrate help effectively
  - Have started with people inside the lab, but outside the Beams Division
  - Moving on to people outside the lab.
- There is still lots to do to achieve longer term Run IIA and IIB goals
  - Current priority is on getting to 5-8x10^{31} by the end of 2002
  - Moving beyond this will require the Recycler and recycling
  - Components of the Run IIB plan exist but are not under active pursuit other than electron cooling
    - ✍ Intention to assign Run IIB project manager by end of this summer

"Run II is a challenge, but at least the accelerator physics is interesting." - M. Church